

JOINTING AS A FUNDAMENTAL FACTOR IN THE DEGRADATION OF THE LITHOSPHERE.

PLATES VI-VIII.

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This paper is the result in part of a study of the various factors of rock weathering and erosion which I began some years ago and which has been influenced further by a study of the effects of marine erosion along the north Atlantic coast.

At a certain point I had the idea of trying to find for mechanical weathering a definite factor comparable to the part which chemical non-equilibrium plays in chemical weathering; further study convinced me, however, that there is one factor which is constantly acting in advance of all other factors of both weathering and erosion, and that this factor is jointing.

In almost all studies and in most textbooks and other geological writings on the subjects of weathering and erosion the matter is usually approached from the point of view of the contact of the atmosphere, and the results of both weathering and erosion are often spoken of as the attaining more or less perfectly of an equilibrium between the surface of the lithosphere and agents of the atmosphere. Thus both the formation of "clay" and the formation of a "peneplain" or base level are regarded as the final products of weathering and erosion; they are the conclusion of a cycle of changes which began in a condition of non-equilibrium, ran through various well-marked stages and ended at last in so-called final products which would or do remain permanent until some general earth change takes place, when a similar cycle will begin anew. If this is a fair statement of the matter, as I think it is, then these are the results of the contact of lithosphere and atmosphere to produce a surface equilibrium.

When, however, the much larger subject of the reduction of the lithosphere in general to a condition of something like equilibrium is considered, these so-called final products of "clays" on the one hand and of "peneplains" on the other are seen to be not final at all but are really the end products of a series of agents which are more or less accidental or local. The second point then upon which I wish to rest a case is that the degradation of the lithosphere including both the factors of weathering and erosion is something which is not essentially atmospheric in its control but is rather something which is a fundamental feature of the lithosphere structure itself; and that all the agents of frost, surface drainage, glacial action, chemical weathering or other surface or atmospheric agents are by their nature essentially accidentals which do influence local results but are not the controlling factors. If I may illustrate the point by an appeal to some other framed structures besides the lithosphere such as the behavior of metals under stress, we may make the comparison by considering the active life or coherency of a pair of car wheels or axles. This active life is conditioned not so much by nature of the particular train of which the wheels or axles are a part but rather by the nature of the steel and also by the fact that it is almost, if not quite, impossible to make masses of steel which will be destitute of flaws which will become joints, or to make a steel which will continue elastic. The fact that one wheel may outlive the other twice over in active service is more a question of time factor than it is of difference of the agent which produced the final break; the eventual cause of the break will in the vast majority of cases be due to some inherent factor in the wheels themselves rather than to a particular agent or a particular occasion or accident. One of the great problems of metallurgy to-day is to produce a steel without joints and it is also one of the problems of geologists when they try to conceive of the lithosphere without these same fundamental lines of weakness which we call joints; almost the only condition of the lithosphere where we can hypothecate no jointings is in a molten mass.

This tendency of earth matter to arrange itself in definite lines of weakness seems to become more striking the farther we investigate the fundamental structure and the behavior of the lithosphere

under geological conditions. Even unconsolidated sands show this same disposition under the atmosphere to arrange themselves in the repeating patterns which are so common in the case of rock masses undergoing disintegration under the influence of the atmosphere. One of the illustrations of this I wish to show is from the behavior of the loose sands which overlie the Talbot formation along the Delaware Coast (Figs. 1-2. Plate VI). These sands are disintegrating and falling in a series of parallel lines which are surprisingly like the joint control of weathering in such a place as the Grand Canyon of the Colorado and indeed in many mountain and other elevated rock structures. This parallelism shown even in these loose sands seems to appear in practically all types of rock structure and would seem to be part of the essential character of rock masses themselves, though I do not in this case, of course, mean that these sands are to be regarded as jointed; I do mean, however, that the shape of the sand under disintegration is something which is due to the nature of the sand itself and is not atmospheric in its original cause.

The literature regarding joints and jointing structures is now large and widespread. It need not be reviewed in detail here as it is general principles that I wish to discuss, not the details of the literature. However, certain general works may be cited. Earlier discussion will be found in the work of Günther;¹ also Günther;² Leopoldt and Peschel;³ Penck;⁴ Supan.⁵ All geologists are doubtless familiar with the discussions, on earth features including joints in the monumental work of Suess on "The Face of the Earth." Later literature references may be found in papers by W. M. Davis in the publications of the United States Geological Survey, and to his papers in the *Bulletin*⁶ of the Geological Society of America.

Those who are interested in the nomenclature of faults and joints may consult the report of the committee⁷ of the Geological

¹ "Lehrbuch d. Geophys.," Stuttgart, 2 vols., 1883.

² "Handbuch d. Geophysik," 2 vols., Stuttgart, 1899.

³ "Physische Erdkunde, etc.," Leipzig, 2 vols., 1879-80.

⁴ "Morph. der Erdoberfläche," Stuttgart, 2 vols., 1894.

⁵ *Grundzüge der Phys. Erdkunde*, 1911.

⁶ Vol. XXIV., pages 187-216 especially.

⁷ *Bull. Geol. Soc. Amer.*, Vol. XXIV., pp. 163-186.

Society of America; Hobbs⁸ in a long series of papers has discussed quite fully the subject of jointing in the relation to earth features and surface conditions. I. D. Scott⁹ discusses joints and fracture systems as effecting relief and control of drainage and gives also a summary of the literature on the general topic of joints. One of the surprising things about this literature in regard to joints is the almost complete agreement among textbook writers in the comparative neglect of jointing as a really important active factor in earth dynamics; the subject of jointing is usually considered as a phase of structural geology rather than as an active controlling agent in the behavior of the lithosphere. This is, I believe, a serious neglect and a condition of affairs which is totally unwarranted by the nature of the subject. One of the chief points I wish to emphasize in this discussion is the proposition that earth fracturing is one of the essential active fundamental geophysical constants akin to igneous agents in the continuity of its action and the universality of its results, that it is inherent in the nature of the lithosphere; no portion of the world as we know it to-day is free from the action of jointing and I believe it can ultimately be demonstrated and proved that this jointing of the lithosphere has been active throughout the past geological history as a general controlling factor in the great geographic and paleographic changes shown by the records of historical geology. Evolution of the lithosphere without the controlling influence of jointing seems to me an impossible hypothesis.

It may be worth while to classify into a few general groups the manner in which jointing is now seen to be a controlling factor in the changes occurring in the lithosphere; among these groups may be cited the following:

- (a) Repeating patterns of authors.
- (b) Control of river drainage.¹⁰
- (c) Coast lines.¹¹

⁸ Details may be found in "Earth Features and their Meaning," New York, 1912; "Earthquakes," New York, 1907; see especially *Bull. Geol. Society of America*, Vol. 15, pp. 483-586.

⁹ Gerlands, *Beitr. zur Geophysik.*, XIII., 1914, pp. 163 ff.; *idem.*, pp. 241-260.

¹⁰ Hobbs, "River Systems of Conn.," *Journal Geology*, Vol. IX., 1901, pp. 469-485. Iddings, *ibid.*, Vol. XII., 1904, pp. 94-105.

¹¹ Hobbs, "Lineaments of the Atlantic Border Region," *Bull. Geol. Soc. Amer.*, Vol. XV., pp. 483-506.

- (d) Boundaries of geological formations.¹¹
- (e) Tectonic control of earthquake shocks.¹²
- (f) Atmospheric weathering such as in the Grand Canyon, boulder weathering, etc.
- (g) Shore lines.¹³
- (h) Valley formation due to faulting under joint control.¹⁴
- (i) Grand features of the earth as related to lines of fracture and block movements resulting therefrom.¹⁵
- (j) Plateau fracturing and disintegration.¹⁶

Other literature might also be cited but these references are deemed enough for the immediate purpose of illustration.

It is evident, then, that systems of fracture along definite lines of direction extending both over wide areas of country and in lines of great length, are to be regarded as playing a major part in lithosphere evolution, and that jointing must be regarded as one of the active agents at work in the behavior of the lithosphere.

The discussions in the literature of the science concerning the origin and nature of fjords illustrate probably as well as any one phase of the subject the attitude of writers toward the relation of joints to earth-structure. Günther¹⁷ gives a résumé of the discussions of theories regarding fjords and groups them into the following classes: The Depression Theory, the Cleavage or Fracture Theory, the Glacial Theory, the Erosion Theory. It will be noted that all but one of these theories seek to explain the origin of fjords upon some basis really exterior to the nature of the lithosphere con-

¹¹ Hobbs, "Earthquakes," New York, 1907, *passim*; includes also reference to other joint literature.

¹² Shaler and Tarr, "Geology of Cape Ann, Mass.," 9th Ann. Rep. U. S. G. S., 1887-88, pp. 529-611.

¹³ Kemp, "Preliminary Report on the Geology of Essex County, N. Y.," Report N. Y. State Geol. Survey, 1893, pp. 438 ff.

¹⁴ Hobbs, *Bull. Geol. Soc. Amer.*, Vol. XV., pp. 503-506.

¹⁵ E. Erdmann and Nathorst, Erdmann, "Descr. de la form. carb. de la Scania," 1873. Royal Swed. Geol. Institution. Nathorst, "Geol. Foren Stock," IX., pp. 74 ff. See also Suess, "The Face of the Earth," Vol. 2, especially for résumé of these papers and also discussions of the structures of the Canadian and Baltic shields. (The English translation by Sollas is the one referred to.)

¹⁶ Günther, "Lehrbuch," Vol. II., 1882, pp. 463 ff.

struction. Thus, Supan¹⁸ says that "There can be no reason to doubt that fjords are submerged valleys," and compares the Laxe Fjord of Norway to the one which would be formed by the submergence of the wedge-shaped Thalbuch of Salzburg, supposing that the sea were to overflow it. This may be perfectly true as far as it goes, but it leaves yet unexplained the reason for the similarity of the structure of the two places indicated and also fails to explain one of the characteristics of fjord coasts and that is their remarkable parallelism of structure, a parallelism which unites their structure with the parallelisms seen in other aspects of the surface of the lithosphere. The fracture or splitting theory is attributed by Günther to Peschel and Leopoldt and may be stated as follows: The destruction and breaking up of the coast was attended with its ascension; originally the cracking or splitting was not farther than the ascent of the greater layers which, in consequence of the uplift, arched over and later the fracturing extended through a shrinkage and diminution of the mass. "The uplift and destruction were simultaneous." It was proposed in brief that the destruction and breaking up of the coast was contemporary with its ascension. The erosion theory and the glacial theory have been involved in the wide discussion in the literature, as, also, may be said of the depression theory. It may be objected to each of these that it uses an agent which is more or less accidental as a primary cause and makes no allowance for the nature of the rock or material structure of the coast and also fails to explain the remarkable parallelism of fjord structures. Moreover, as has been indicated in the literature quoted, there are numerous other places to be observed where the present structure of the lithosphere would produce a fjord coast if it were to come in contact with marine erosion; the Grand Canyon area, also the canyons of the Yellowstone and indeed the parallelism of small stream valleys such as may be seen in the Appalachian folds near Harrisburg, for example, possess the necessary physical structures to produce a parallel indentation of the coast, supposing that some agent of erosion, such as glaciation, were to be involved. Glaciation then and marine erosion are to be regarded as accidents, not as the primary cause of fjord coasts. Even if we assume that

¹⁸ *Op. cit.*, page 579.

fjords are submerged valleys, that still does not explain the parallel structure which is to be observed on both sides of the north Atlantic coast; indeed, the similar character of the rock structure on the north Atlantic coast, in America and Europe both, and in the islands of the Arctic Sea, demand a general structure rather than simply a general agent.

When the discussions of principles concerning fjord structures are applied generally to a wide tract of the earth's surface, such as for example the North American continent, certain points may be shown, and I wish to suggest that that part of the North American continent included between lines drawn from the mouth of the McKenzie river through Great Bear Lake and Great Slave, Athabaska, Winnipeg, and the Great Lakes and another line drawn from Cape Cod to Nova Scotia parallel in general with the St. Lawrence river up to Newfoundland, is controlled by a series of master joints whose general angles of direction may be read from the lines of present sea-coast, lake distribution, entrance of sea channels, bays and harbors and that these are all to be conceived of as essentially attributable to a general cause which is independent of local conditions and is an essential part of the structure of the North American continent. Further, that this great extent of continental land has been in the past and is now, although it is often regarded as one of the fixed segments of the lithosphere, undergoing disintegration and degradation in a manner controlled essentially by something which is independent of atmospheric contact and may be explained on the supposition of the falling apart of a series of segments of the earth due to the development of these lines of jointing. I conceive this disintegration and development of jointing to be due to the loss of elasticity in this portion of the lithosphere. This mass of the continent has been since Archean times loaded repeatedly by the reception of sediments extending from early Paleozoic to Mesozoic times, it has been flooded from time to time by water, overrun by glacial ice, and even if not presumably subjected to elevation or subsidence it has nevertheless been subjected to a series of earth pressures and strains so that a series of master joints have become a primary part of its structure.

That under the combined attack of atmospheric weathering in

its various aspects, and also under the attack of the forces of the sea, these joints have become great lines of weakness, so that the whole outer portion of the lithosphere is here undergoing a profound and far-reaching disintegration. This sequence of events of repeated loading by sediment and erosion of the surface by ice caps has produced a wornout condition of the lithosphere structure at this point, so that even if we regard the Canadian Shield, and analogously the Baltic Shield, as one of the fixed segments of the earth, we may still observe that it is undergoing degradation just as other surfaces of the earth are undergoing degradation. The fact that it may be regarded as fixed so far as up and down motion is concerned does not conceal the further fact that under the loading indicated the mass has lost its elasticity as a steel mass will eventually lose its elasticity and will be subjected to falling apart. It is possible, then, to regard even the fixed positive elements or horsts as subject to disintegration and reduction through combined jointing and marine aggression, in other words, it is possible, in my estimation, to demonstrate a reduction of the lithosphere below sea level. As I conceive the situation we are witnessing, in short, the destruction of a continental mass through the combined effect of forces from without and from the inherent weaknesses which have been brought about through past geological conditions; that finally we have here not so much a rise or fall of land as we have of lithosphere planation or reduction upon a grand scale, and that this planation is hastened and largely induced through the weaknesses in the continental mass itself.

It may further be seriously questioned whether the "peneplain" of this Canadian area may not eventually have to be regarded as due rather to marine denudation rather than to atmospheric erosion. One of the objects of this study has been to consider the old and now somewhat neglected subject of marine denudation in connection with the modern study of joints. Further details of this will be considered later in this discussion.

Since there is stratigraphic evidence for believing in the existence of former land connection across the northern hemisphere with perhaps former water channels leading down into the present Europe and North America the question of the disintegration and degrada-

tion of this land mass becomes one of considerable interest in the physical history of the area in discussion. That the usual processes of land surface erosion and continental degradation are not enough to explain such continental destruction may possibly be a matter of opinion rather than absolute proof. However the coal beds and flora of the Pennsylvanian found in Spitzbergen, the occurrence of Mesozoic deposits across practically the area of the northern part of the hemisphere, the similarity of certain vital groups on separated areas of this vast tract of the earth argue for the existence of such a destroyed land mass, a land mass which has left its relics in the form of islands in the arctic sea, in the form of indentations and multitudes of channels and in the similarities which are to be observed in the structures of the Canadian and Baltic provinces.

The literature concerning some of these arctic islands is referred to elsewhere in this paper but from their present situation and methods of destruction I believe the explanation of the destruction of this former land mass lies essentially in two things, a definite structure in the lithosphere itself and in marine denudation or degradation; thus showing in the combination of these two elements the fact of land or lithosphere surface degradation below sea level. It is of course true that other forces such as change of sea level may be involved in this. Since the descriptions given of the marine degradation now in progress at Spitzbergen indicate a very definite joint control both in the lines of fracture and in the vertical faced cliffs caused by marine erosion acting against a jointed structure of the rock, we may explain this along precisely the same lines that the disintegration along the coast of New England and in the islands of Casco Bay may be explained, that is, by jointing and the disintegrating effect of marine and atmospheric attack. The theory that the Canadian Shield¹⁹ is a peneplain and has been so since Pre-Cambrian time, is not interfered with by this suggestion; it is rather all of it involved in an attempt to explain this and other great continental degradation upon more definite ground than the usual processes of atmospheric agents acting as the forces of erosion. I believe it is possible to show that below the zone of ordinary base leveling or peneplanation lies a still further zone of possible degradation through

¹⁹ Pirsson and Schuchert, "Textbook of Geol.," pp. 556 ff.

the destructive influence of those joints which are part of the fundamental nature of the lithosphere itself.

The old problem of marine planation which was so much discussed by the geologists of the former generation had at least elements of truth in it, elements which are, I believe, covered by the mutual action of joints and marine attack producing degradation of the lithosphere below sea level. So that marine planation does act to produce a further degradation of the lithosphere below the base level of erosion or below Davis's peneplain. That to restate the point, weathering and surface erosion proceed by the usual well observed methods and reduce the lithosphere to residual sands, clays and peneplain but this does not complete the possible further degradation of the surface of the lithosphere because the joints which have developed as one of the primary features of the lithosphere extend on down below sea level and granted an agent of transportation, for instance the sea, and its currents and tides, there is still the sub-base level process of degradation proceeding. It must be remembered that the sea is one of the most powerful reducing and transporting agents known and acts always against the continental masses somewhere, so that a system of jointing once started and the sea playing against it, the action of reduction is carried along rather quickly as geological time goes. I have personally observed in the garnet-mica-quartz schist rocks south and west of Portland Harbor, Me., the complete reduction from jointed blocks in the sea cliffs down through various stages of pebbles and gravels to sands which are composed of quartz sands and the garnet crystals from the mica schists, while the mica is by tidal action carried out beyond the shore to deeper water (Fig. 3. Plate VII).

I put some considerable emphasis upon this because the actual beach evidence and the evidence from sands and gravels on the fore-shore in many cases fail to show all the intermediate stages so that there is here suggested the possibility of many coarse and fine sands in the older geological formations having been formed by a process of rapid joint splitting, beach grinding and tidal distribution of the residue. The rapid accumulation and great diversity of sands, gravels and conglomerates of the Pottsville, for instance, may have been due to such combined action of a jointing structure and a rapid

agent of grinding. In the case of the Pottsville one of the marked features of it is the occurrence at variable intervals of massive siliceous conglomerates which alternate with fine sands and coal beds. David White²⁰ has summarized the literature in regard to the Pottsville and the following quotations are from his paper:²¹

"the Pottsville formation is in the type region composed chiefly of massive siliceous conglomerates . . . which comprises a series of ponderous conglomerates which are more variable in color, composition and assortment in the lower part and more quartzose, dense and light colored near the top . . . and are interspersed with a number of carbonaceous beds workable over considerable areas. . . . The conglomerates intercalated in increasing proportion in the upper beds of the Mauch Chunk consist of irregularly bedded poorly assorted or sometimes apparently unassorted pebble or boulder accumulations in a matrix of coarse arkose sands colored by reddish or greenish shale washes. The pebbles are mostly of quartz, though sandstone, syenite, chloritic schist, limestone and even red and green shales and conglomerate fragments are also present. Occasionally the pebbles which are sometimes subangular attain a diameter of 3 or 4 inches or more; . . ."

Further in the same report (pp. 861-863) White discusses the occurrence of these conglomerates and their possible origin and says:

"The remarkable strength and varying activity and direction of the movements of the early Pottsville sediments over the Mauch Chunk delta in the Schuylkill-Swatara region during a period of oscillating tide level are proved by the alternation and high degree of irregularity in the Pottsville beds, by the transportation of the conglomerate building material to a long distance from the present margin—*i. e.*, by the long radius of the fan—and by the size of the boulders which are sometimes encountered far from the margin of the field. In illustration of the latter circumstance, the occurrence of boulders, 7 or 8 inches in diameter in Head Mountain, described by Rogers ('*Geol. Pennsylvania*,' Vol. II., pt. I, p. 22) may be cited. . . . The interruption of the general subsidence by short periods of elevation and stability . . . accounts also for the readiness with which the conglomerated sediments, which usually almost directly, when not immediately, overlie every Lykens coal, were swept across the carbonaceous deposits on the recurrence of the general downward movement."

White, in discussing the origin of these Pottsville sediments of so pronounced a character, seems to fall back upon the idea of a rapidly depositing series of coarse sediments washed down from high lands back. (See quotations as above.) There are indicated

²⁰ David White, "The Stratigraphic Succession of the Fossil Floras of the Pottsville Formation, etc.," 20th Annual Report of the Geol. Survey, U. S., pp. 749-953 (Part 2).

²¹ *Idem*, pp. 762-763, 861-863.

here certain physical conditions which are favorable to the prevalence of jointing influence. These are the marked mechanical nature of the disintegration and the rapidity of deposit of the sediments before chemical weathering or disintegration had had time to act, the repeated occurrences of coal swamps overrun by heavily bedded gravels which indicates an unstable rock equilibrium favorable to the idea of the presence of joints; and finally the presence of subangular blocks and large pebbles and boulders shows a rapid mechanical disintegration. It would seem to be evident then that the accumulation of conglomerates, such as in the Pottsville, demand a rapid mechanical disintegration running ahead of chemical weathering, and a grinding and transporting agent to reduce the joint blocks to rounded boulders, pebbles and sands before chemical disintegration has time to occur. This, it will be observed, is practically the same idea as shown in the formation of arkose sediments generally. This point will be discussed later in connection with the similar formations in the Newark formation. This reducing agent referred to need not necessarily be marine. In the small tributaries to the Monongahela river, small streams flowing rapidly down slopes across jointed beds of sandstone, limestone and shale, I have frequently collected rounded oblong pebbles 6 to 8 inches in length and also roughly rounded rectangular blocks of limestone which are manifestly the result of surface erosion and grinding on blocks due to jointing. The shales under these conditions pass rapidly to muds and are borne along to make river flats, alluvial plains upon which river and stream ice might deposit the larger pebbles and even the angular fragments; the ability of river ice to do this is a matter of fact proven by observation. The dry summer stages of such tributary streams show many such cases of comparatively contemporary joint degradation; often the original joint structure would have to be inferred from the nature of the surface gravels if it could not be seen in the immediately adjoining hills.

In the case of marine planation there is also the further fact that an increase in the encroachment of the sea upon land masses acts in a manner analogous to the rejuvenation of a stream by elevation of the land surface, it increases its cutting and transport-

ing power and also increases the rate of land degradation. Thus the factor of jointing serves to unite processes of atmospheric and marine degradation and because it has probably done so in the past as well, it enters into the problem of paleogeography. The transgressions of the sea, the filling of old sea channels and bays by masses of jointed limestone, sandstone, or the clay rocks, material which would rather readily reduce to sands and gravels and muds, all become factors which may eventually perhaps be shown to be due to jointing degradation. The interbedded limestone conglomerates observed by Logan, Prime, Walcott²² and others certainly suggest a method of origin involving both a mechanical method of rapid erosion and also a time interval between the deposition of the original limestone layers and their subsequent breakdown to gravel or even boulder form. Anyone who has personally examined these conglomerates in York County, Pa., can have no doubt as to the angular nature of the fragments of the conglomerate and Walcott (p. 39, op. cit.) refers to the "angular fragments of limestone with sharp, clear cut edges" in the redeposited conglomerates; in some cases these boulders are "from 3 to 4 feet" in diameter, these last from Tennessee. In discussing the origin of these conglomerates Walcott believes "that the sea bed was raised in ridges or domes above the sea level and thus subjected to the action of sea shore ice, if present, and the aerial agents of erosion. . . . The inference is drawn that the debris worn from the ridges was deposited in the intervening depression beneath the sea." Walcott does not consider jointing in this connection at all though it may be regarded as a necessary adjunct for more than one reason. For one thing it is very much to be doubted if marine erosion as hypothesized could occur unless the rock masses of the limestone were already in some separated block form, ready to be torn apart and beaten about by tidal action; if on the other hand erosion against a sea cliff or against a mass of rock exposed to atmospheric weathering be regarded as having occurred we must again, in the case of limestone, believe that jointing was the predominant factor as otherwise the limestone would be reduced to weathered residues

²² Bull. U. S. G. S. No. 134, pp. 34-40; pls. X.-XIV. Especially p. 36 and p. 39.

which would be much slower in their accumulation and would hardly be in block or even pebble form at all. Secondly the elevation of the original beds could scarcely have come about without fracturing as there is no reason to suppose that the beds were so deep seated as to come within the "zone of flowage," the elevation was not probably great and would under the circumstances be included in the zone of fracture.

From the paleogeographic point of view the subject is possessed of possibly more than passing interest because of the fact that it introduces into the study of unconformity or non-conformity a means of determining the time factor, and also the means of determining the fact of a break in the succession of deposition, and it may also serve to determine the fact of a stratigraphic break without the recession of the sea. Walcott's idea of the events of the formation is practically sub-marine planation, a thing which could hardly occur without a very rapid cause of breakdown in the limestone, such as would result from jointing.

I have no desire to burden the nomenclature of the science with any new terms, but the idea of jointing causing a record of a disconformity which would otherwise be lost seems to me worth the notice. If the displacement of the lower limestones had occurred without jointing it is most probable that there would not have been enough disintegration to have left any record unless the time interval had been long enough to bring about the usual atmospheric weathering. In the physical conditions supposed by Walcott the development of jointing would also act to prevent the persistence for any great length of time of a barrier to faunal migrations.

In connection with the discussions of the conglomerates of the Pottsville above, reference is made to the arkose conglomerates and sands of the Newark. Since the granite pebble conglomerates of an arkose character are now to be observed in formation along the coast lines where rock disintegration and degradation are controlled by joints and may easily be seen to be so, as along the coast of Maine for instance, I believe it to be probable that the arkoses of the Newark of the Atlantic coast states are also due to rock destruction caused by joints, inasmuch as the sediments are composed of materials which show a mechanical disintegration always in ad-

vance of chemical weathering. In this case the destruction and degradation would follow upon the previous history of the region.

The disturbances of the Appalachian Revolution had brought about a condition in the rock masses involving both folding and fracturing. During the closing stages of the Pennsylvanian, and most probably for some time after the close of this time proper there were conditions of non-equilibrium, the position of the sea level was not probably fixed but was in an oscillatory condition. This condition of the lithosphere in that portion of the North American continent now known as the Atlantic border would involve a system of rock structures in which by successions of strains, folds, shiftings of sea level, the elastic resistance had been destroyed. The rock masses would pass by variations of uplift and erosion into the zone of fracture as well as the zone of folding. The Newark time would appear then as a time in which the strains of the previous time era had developed a great mass of fractured and jointed rock as the outer portion of the lithosphere.

The physical conditions of the continent east of the present Appalachian mountains were manifestly very different from those west. What it was that induced the great degradational movements to form the thick deposits of the Newark must be somewhat a matter of conjecture. That it was rapid is indicated by the nature of the sediments, that it did not in large parts of the area follow long periods of thick accumulation of a soil cap from chemical weathering would also seem to be a legitimate conclusion from the pronounced mechanical nature of the sediments, as the granitic sandstones for example.

The character of the early Pottsville sedimentation together with the Newark series as described from its series along the eastern states would however seem to call for an explanation based upon the idea of a quick mechanical rock destruction and transportation such as jointing would induce. The fracturing of the surface formations of the lithosphere had probably already occurred, there was needed the agent to separate and remove the segments small and great due to this fracturing. This might have been just as it is now in various portions of the earth due to steep surface drainage, glaciation or any one of the active means of transportation.

The closing stages of the Permian have been supposed to show even in North America evidences of glaciation. This may have been sufficient to explain some of the arkose sandstones but there hardly seems to be enough evidence at hand to hypothecate this as a general condition extending into the Newark. All that I am endeavoring to demonstrate is the fact of a physical condition in the surface portion of the rock structure favorable to easy and rapid disintegration rather than to try to establish any one particular means of the transportation of the broken rock fragments.

On the edges of the Canadian shield or "peneplain" as it has been called and along the edges of the continent bordering the Gulf of Maine may be seen in active operation to-day the results of a jointing structure to hasten marine erosion; this is taking place now after glaciation has removed the surface soil cap, the jointing is now fully exposed to whatever means of rock transportation may be at hand.

From the fact that practically all stages in the formation of granite sand, pebble and boulder flats may be observed in progress along this coast we may reasonably infer that the formations out beneath the low tide level extending over the continental shelf would show the marked characteristics of a marine arkose analogous to the continental arkoses of the Newark. There would thus seem to be recurrent eras of a rapid joint degradation differing from the longer periods of the usual chemical weathering and erosion, these periods following either periods of earth strains or periods in which after removal of the soil cap jointing would then proceed to a further reduction of the lithosphere.

Jointing, then, acts as a connecting factor in uniting continental and marine erosion into a process or series of processes which, so far as the lithosphere is concerned, are consecutive. Here again the real controlling factor in the degradation is the structure of the lithosphere itself, not the particular agent, because, conceivably, surface continental erosion followed by marine erosion are simply two stages of a general degradational process. There must have been in former geological times reduction of the land surfaces after the completion of a cycle of erosion; it does not follow that every

base level produced by erosion was followed by a rise of land masses and a return of the cycle of erosion, and so on to an indefinite extent. From what has just been stated previously it will be seen that I conceive these fundamental earth joints to have played an active, possibly a controlling, part in paleographic history. The connection and disconnection of land masses, the opening and closing of channels of sea migration, the filling up of channels by the rapid formation of beach gravels and tide flow; the formation of tide and sand flats and boulder and pebble flats (Fig. 4. Plate VII) such as are so common along the upper Atlantic coast line (glacial in many cases, no doubt, but still due to jointing), must all have played their parts in past geographic changes of both land and sea. The jointing which may doubtless be observed in the Alaskan coast in the neighborhood of Behring Sea, would, under these circumstances, be an active factor in the separation of land connection between America and Europe, and Asia.

Furthermore, according to this hypothesis of joint control, the destruction of a great continental mass of land across the northern hemisphere, which seems to be indicated by the fact of the relics of such a mass in the islands of the north of Europe and North America, and the distribution of islands in the Arctic Sea, all with their connected deposits of Paleozoic and Mesozoic, becomes a possibility explainable upon more definite grounds than simply the hypothesis either of sea aggressions alone or of glacial or other erosive processes alone. This continental destruction is indicated by the character of the sea cliffs of Spitzbergen and their rapid angular disintegration and the reduction of the lithosphere through a series of blocked islands which are now disintegrating under the structural weakness of joints and the transporting power of marine erosion. The details of this may be seen by reference to the literature. Thus the islands of Franz Josephs Land, Spitzbergen, and Bear Island in the Arctic Sea have been appealed to by various authors in illustration of the theory of jointing. I. D. Scott²³ and Hobbs²⁴ reproduce the figure from the original exploring expedi-

²³ *Op. cit.*, pl. 2.

²⁴ Hobbs, *Bull. Geol. Soc. Amer.*, Vol. 22, pl. 8, Fig. 2.

tion.²⁵ The description²⁶ given of the breaking down of these island masses is that of the remains of a plateau structure shown throughout the island group, with fjords which are characteristic alike of the small islands and "the mainland." Against these island remnants of a plateau carrying the remnants of the horizontal layers of Carboniferous, Permian and Miocene deposits "the sea unceasingly beats in the further destruction of the fragments of the plateau, while strange pillars and towers indicate the wide extent of the islands" destroyed in this way. This description with the illustrations given in the literature referred to shows plainly enough the destruction of the land masses by lines which are manifestly joint lines, and is fairly characteristic of similar sea coast shapes to be seen along the shore of the North Atlantic ocean both on the American and European sides.

These towers and pillars referred to are strikingly similar to some structures referred to in a recent valuable paper by Barrell,²⁷ in which the origin of certain plains along the eastern Atlantic coast is connected with former marine erosion. The discussion of this paper brings out the question of marine origin for those upstanding land masses commonly known as "monadnocks."

Those interested in the arguments for the fact of marine planation along the Atlantic coast of North America should consult Barrell's paper.

It has long been a thought of mine that it might be possible to have established some time the demonstration of "monadnocks" being residues left from a jointing structure in which mechanical disintegration had played a predominant part. As may be seen in the discussion of the paper referred to this idea is inherent in the conception of marine plains as developed by Barrell.

In the largest view of the matter Bear Island, Spitzbergen and other like land remnants are "monadnocks," if by this term is meant any residue of a former land surface which stands as a segment not now reduced to a general level. This sort of residual

²⁵ Norske Nordhavs Exped., Bd. 5; also *Peterm. Mitteil.*, 1870, S. 249 ff. Other references and a German translation will be found in "Unser Wissen von der Erde," von A. Kirchoff, Vol. 3, pt. 2, pp. 394 ff.

²⁶ "Unser Wissen," etc., as cited pp. 395 ff.

²⁷ *Bull. Geol. Soc. Amer.*, Vol. XXIV., 1913, pp. 688 ff.

land surface is not however to be explained by ordinary land erosion, nor does marine erosion explain it any more easily unless there be entertained at the same time the conception of some structure such as the joint segments here discussed. Steep cliffs and deep fjords do not per force mean a sunken coast line primarily, they may be I conceive land or rock shapes due essentially to great joint lines.

That there exists observed evidence for believing in the ability of a jointed structure to induce a breaking down and destruction of plateaux is shown by the investigations of E. Erdmann and Nathorst.²⁸ These investigations were carried out in the structures of *Scania*, an old province in southern Scandinavia and in the opinion of so able a critic as Suess justify the opinion that

"*Scania* is formed of fragments of a great plateau broken by joints. . . . As E. Erdmann has shown the whole region is traversed by great longitudinal fractures which run from northwest to southeast; along these the whole country has been let down irregularly with the formation of troughs and horsts."

The investigations of Nathorst have shown further that this subsidence has taken place at different times,

"and that it is possible to classify the fractures according to their age. . . . In this country which has not been subjected to any folding since the Cambrian period we have a new and instructive example of the breaking down of a tableland accomplished piece by piece." (Suess, *op. cit.*, Vol. 2, p. 48.)

Some of the fractures present have been determined by Nathorst as older than the Trias.

There exists then more than simply hypothetical ground for considering jointing as one of the great fundamental shaping factors of the earth. The essential unity of the great mass of the upper portion of the northern hemisphere will probably be shown more and more as stratigraphic investigation on both the continents of Europe and America proceeds. This unity is already shown however in the similarity of structures now to be observed over widely separated areas, in the analogies if not actual parallelisms along the northern coasts and arctic lands where marine denudation is

²⁸ See citations given earlier in this paper. Their studies are reviewed by Suess in Vol. 2 of the English edition of "The Face of the Earth," 1906, pp. 46 ff.

proceeding by a method which can rationally be explained only upon the basis of some generally determining cause such as the jointing which is shown with practically universal distribution.

That such block or fracture destruction is even now proceeding over portions of the land masses is believed to be true; certain structures in the British Isles (universally regarded as remnants of the former wide extension of Europe) more especially in Scotland point to a decided indication of such block disintegration or fracturing. The approximate parallelism of the Hebrides, the Faroe, the Orkney and the Shetland islands; the same parallel indentations of the coast lines, the remarkable series of firths which find their greatest and most striking expression in the vast gash which almost cuts Scotland into two parts as the firth of Moray passes into Loch Sess and this on into Loch Linnhe and ends at length in the firth of Lorne, all these are so striking in their relations and occurrence that the conclusion is almost forced on us that here also is to be seen the illustration of a land mass passing into block disintegration by a series of fractures which exist independently of surface agents of weathering or of erosion.

As the whole mass of the northern hemisphere is contemplated in its upper parts, with its widespread likenesses, its analogies of structure and its broken remnants of former continuities to be observed in the sediments of the arctic islands and in America and in Europe, the reason for this unity of structure and unity of disintegration must be sought not in the atmospheric elements which have played upon it but must be sought for in the essential nature of the lithosphere itself.

As we journey round from lower Europe about the Canary and Madeira islands up through the British islands to Scandinavia, on through the arctic seas and islands and so on down the American coast there is everywhere shown the same disintegration of the land mass by a factor which controls all the atmospheric and erosion agents; there is seen a mechanism which whatever agent plays upon it, whether glacier, frost, expansion and contraction from change of temperature, or from the ceaseless pounding of the sea, still runs always far in advance of them all and reaching even below the level of the sea and the atmosphere determines in advance the

destruction of the land mass. This factor is the presence of joints.

Connected with the problems of the degradation of the lithosphere is the necessity of meeting the problems of the reduction of former continental masses leaving now only residues of them as islands or separated continental units such as Africa, Australia and other masses believed to have been united formerly into the Gondwana Land of authors.²⁹

Here also is to be included *Eria*, the former great continental mass extending across the northern half of the globe.

Some geologists would meet this problem by disputing in the first place the existence of such continental land masses, as Gondwana, and hold firmly to the theory of permanent ocean basins. That this idea of permanent ocean basins is a widespread and deeply rooted one is well enough known to need no special proof.

We may note, however, one reference to it from one of the older textbooks—thus Geikie:³⁰

“From early geological times, the present great areas of land and sea have remained on the whole where they are, and that the land consists mainly of strata formed of terrestrial débris laid down at successive epochs in the surrounding comparatively shallow sea.”

“Without this continent, [*Eria*] on the other hand, paleontologists cannot explain the known distribution of Permian land life, and, further, its presence is equally necessary for the interpretation of the peculiar distribution of marine faunas beginning certainly with Devonian and ending in the Cretaceous.”³¹

Connected with this is the related idea of a former worldwide Mediterranean, the Tethys of Suess which extended around the globe as a great encircling ocean of which the present Mediterranean is a remnant.³²

The problem then is not one which can be dismissed by disputing the matter in the first case because the weight of evidence is against such a position, and the stability of the sea floor is an hypothesis which rests more on supposition than proven fact, while

²⁹ Convenient reference may be made to Pirsson and Schuchert, “Text Book of Geology,” Vol. 2, *passim*; also Suess, “*Lethea Geognostica*” of Frech, Paleozoicum, contains maps of Gondwana.

³⁰ Geikie, “Textbook of Geology,” 3d ed., rev., p. 650, London, 1893.

³¹ Pirsson and Schuchert, “Textbook,” Vol. 2, p. 761.

³² Pirsson and Schuchert, *op. cit.*, p. 761.

the belief is more and more growing among geologists that the lithosphere is governed by processes and laws which act generally to its total mass and not locally or in limited portions. Thus the idea that the laws which govern the general behavior of the lithosphere cease to act or change their character in that portion of the earth under the hydrosphere seems to me untenable in the first place and unproven in the next.

The "repeating patterns" of various authors³³ if they mean anything at all must involve some general fundamental character of the structure of the lithosphere, a character which under stresses in the mass of the lithosphere would be as likely to occur under the oceans as under the atmosphere contact. It is hardly reasonable to attempt to dismiss these repeating patterns as due to "chance,"³⁴ they are too widespread and have been too often described and identified with fundamental structures in the lithosphere. So that the principle involved in repeating patterns as indicating a definite characteristic of the lithosphere may be accepted certainly as a constructive working basis if not yet generally accepted as one of the proven facts of geophysics.

Applying then this principle to the mass of the lithosphere under the hydrosphere it should be possible to determine from the distribution of islands, volcanoes, coral reefs and other features, systems of joint control beneath the hydrosphere analogous to the systems of joint control of continental surface features beneath the atmosphere. In short the control of the lithosphere surface beneath the oceans by joints I regard as being of equal value and importance as the control exercised by jointing in the lithosphere beneath the atmosphere.

Owing to the comparative ease with which islands on the continental shelves may be shown to be parts of the masses of the continents, and, as in the very remarkable and beautiful example shown in the islands of Casco Bay in the Gulf of Maine, demonstrated to be distributed along lines governed by jointing the problem becomes really complex and more difficult of proof when con-

³³ See especially Hobbs, "Repeating Patterns in the Relief and in the Structure of the Land," *Bull. Geol. Soc. Amer.*, Vol. 22, pp. 123-176, 1911.

³⁴ *Bull. Geol. Soc. Amer.*, Vol. 22, p. 717 (discussion).

sidered in connection with the islands which lie out beyond the shelves of the continents in those portions of the oceans which are generally regarded as separate and distinct from continental structure. The connection of the repeating patterns and joints may be demonstrated from the structures along the New England coast and as it illustrates the principle referred to will be described in some detail. The particular problem here may be stated as follows: to show in the first place that the lines of distribution of the islands, bays, harbors, reefs, and other land masses in the Gulf of Maine are arranged in some definite structural relation with each other and with the rock masses of the main land, and secondly to connect this structure with processes of degradation above and below sea level. If this can be done and certain lines of uniform control shown to be present it is then proposed to apply the same line of reasoning to oceanic islands which are now not so connected with adjacent land masses as those islands in the Gulf of Maine are, and try to show that lines of jointing have been in control of the distribution of these islands; and lastly that lines of joint control being a factor in the behavior of the lithosphere we have here a general agent controlling the degradation, that is the lowering, of the lithosphere surface irrespective of whether the other agents present are variations of atmospheric or of hydrosphere contact.

Part of the demonstration of marine planation in connection with the New England coast has been rendered unnecessary by the publication of Barrell's paper just referred to; this being published after I had begun my own investigation. However, this paper establishes the point which may be regarded as of very great importance, and that is the demonstration of former widespread plains of marine origin rather than simply plains due to atmospheric means of erosion and degradation. In connection with these New England plains may be mentioned also the terraces of the Maryland Geological Survey³⁵ such as the Wicomico, Sunderland, Talbot, etc., terraces which are undoubtedly of marine origin, though not necessarily of joint control in any manner, but built on older marine plain development. It is desirable, however, for the sake of the argument to show some of the character of marine

³⁵ Maryland Geological Survey, Pliocene and Pleistocene, Baltimore, 1906.

planation at present in action along the New England coast. The data mentioned are taken from personal observation of my own and part from the published literature on the subject. Particular reference may be made to the following sheets of the U. S. Topographic Folio, namely, Casco Bay, Portland, Booth Bay, Bath, Penobscot and the following hydrographic charts, Nos. 106, 107, 315, of the U. S. Navigation Bureau, and also the U. S. Coast Pilot,³⁶ for details as to soundings, situation of reefs, bars, islands and harbors. It is not necessary to give the details of this.

The shore of the coast of Maine is almost a continuous succession of rocky points, entrant bays, steep cliffs, or outlying islands and reefs, all connected more or less by sand bars, sand dunes, necks, tidal flats or by back lying marshes. Out beyond the actual shore or strand line lie in addition successions of islands, reefs and rocky points, these all practically being composed of the same sort of rock as that exposed along the shore and with some rare exceptions are not to be distinguished from the rock masses in connection with the mainland or shore line except by the fact that these outlying masses are surrounded entirely and continuously by sea water. The topographic features about Portland Harbor and Casco Bay will illustrate sufficiently these various features. The most marked feature of Casco Bay is the extraordinary number of islands, rocky points and reefs which, as may be seen in the various publications referred to, are arranged in a general parallelism and in a northeast-southwest direction. This direction is practically the same as shown by the prevailing dip and strike of the rock masses about this portion of the Maine coast. These Casco Bay islands are so eminently arranged in repeating patterns as to suggest, even without the necessity of any actual plotting being done, definite lines of joint control, the submerged reefs as may be seen in the navigation charts are frequently continuations of the same jointing structures. If the general lines of jointing and the prevailing lines of strike be compared with some of the small islands and necks near Portland Harbor, the general connected structure of all is apparent. Thus, for example, at Prouts Neck, near Port-

³⁶ U. S. Coast Pilot, Atlantic Coast, Parts I, II., St. Croix River to Cape Ann. Washington, 1911.

land Harbor, the present distribution of islands and reefs shows the same general lines of direction and the same construction as the lines of distribution in Casco Bay. Indeed they are all parts of the same general structure. Prouts Neck itself I have determined to be a structure composed of a series of parallel reefs covered in part by glacial pebble flats, sand dunes, peat bogs, cedar swamps and contemporary pine wood; the pine woods are now growing mostly over sand dunes which lie across the old lines of parallel reefs. These lines of reefs are shown at certain intervals along the direction of the Neck and are parallel with similar lines of islands and reefs which lie out to seaward from Scarboro Beach, often appearing as isolated masses of rock, in many cases now surrounded by bogs or sand dunes. The Neck ends in a mass of rock probably formerly an island in which the same general direction of dip and joint distribution may be seen. The sea encroachment on Prouts Neck itself displays the same joint control of steep cliffs, angular block fragments and contemporary pebble and shingle beaches, such as are common on both sides of the north Atlantic coast. When these lines of Prouts Neck are plotted as to general position and direction they fall into the same scheme as shown in the other structures in Casco Bay. This cannot be regarded in any manner as accidental, but part of the same structure common to this portion of the lithosphere.

The structures around Bath, Booth Bay Harbor and similar places along the coast of Maine, are usually referred to as indicating processes due to glaciation³⁷ or are regarded as evidence in regard to a displaced coast line, all of which may be perfectly true, but it does not disguise the fact that these structures again may be plotted along a system of lines of jointing. In fact, I regard the entire distribution of islands, reefs, flats, etc., within the Gulf of Maine, not as remnants of the former surface of peneplanation, due to atmospheric erosive agents, but as structures due to the combined action of marine planation and essential lines of weakness due to jointing in this portion of the lithosphere, so that the

³⁷ See Shaler, "Geo. Hist. of Harbors," 13th Ann. Rep., Pt. 2, U. S. G. S., pp. 114-118, 1893.

repeating patterns may be carried out here into the idea of marine planation to reduce the land surface below the ordinary base level.

This, I take it, is another way of stating one of the points of Barrell's paper, referred to above, that in the plains adjacent to the New England coast upstanding structures such as the "Monadnocks" of authors, may be regarded, as the towers and figures referred to off the coast of Spitzbergen, as indicating outlines of marine planation.

I hope to discuss in a later paper some further details of this in regard to some structures about Portsmouth Harbor.

The relationship of marine planation to what has been developed as the theory of peneplains is thus a very far reaching problem. That the known action of the sea to wear away the land mass has been underestimated and neglected is perhaps due to the fact that no constant or nearly constant factor to hasten marine degradation has been taken into consideration. The reasoning of some of the older authors would seem to have been based upon the things which are to be observed only as results of local storms and also fails to consider the possible factor of the nature of the lithosphere itself as an active contributing cause in hastening the reduction of the land mass.

Some very interesting discussion of the arguments pro and con of marine denudation or degradation may be found in the various editions of A. Geikie's well-known "Textbook of Geology." Thus (3d ed., rev., p. 448) Geikie says:

"But were it not for the potent influence of subaerial decay, the progress of the sea would be comparatively feeble. The very blocks of stone which give the waves so much of their efficacy as abrading agents, are in great measure furnished to them by the action of the meteoric agents."

Taken in connection with the more recent studies in jointing as controlling rock disintegration, and in connection with what may be seen along the continental borders both land and marine the above statements will be seen to be an incomplete statement of the factors in the case.

That entire continental masses may not be seen to have been reduced by this marine planation should not prejudice the case, it is exceedingly improbable that any one agent alone has ever re-

duced any considerable continental mass; nor should the value of a factor be judged simply from the lateral extent of its spread. The investigations of Barrell already referred to would certainly indicate if not prove that marine aggression has played a most important part in the leveling of the land surface.

It may be worth while to note further that jointing is not simply a vertical matter, it seems so under certain forms of atmospheric attack but under the transporting power of a sea aggression climbing the land surface the development and the existence of horizontal joint lines will accelerate the rate of land degradation in a manner analogous to the acceleration of stream erosion due to change of level.

It is interesting that almost all of the illustrations chosen by Geikie show the controlling action of joints to shape not alone the cliffs but to accelerate the action of marine erosion yet he gives but incidental reference to the presence of joints, and seems to lay most emphasis upon the aerial agents though each illustration given shows in nearly every instance the effect of the controlling action of joints. Again I venture to state that the object of this study in most part is not to claim for either land or marine degradation the superiority as a universal agent of land surface reduction but to try to establish the fact of the presence of one factor which may be regarded as controlling both and which under conditions, favorable now to land erosion, now to sea erosion, enters as the dominant medium for shaping the resulting surface of the stony portion of the earth more technically known as the lithosphere. And that in the nature of the relation of the three elements of the earth, atmosphere, hydrosphere, lithosphere, the attempt to restrict the forces of lithosphere degradation to an assumed base level fixed by the sea level is an untenable position. Untenable because of the fractured nature of the rock mass itself and also because of the fact that the sea level is not constant, so that whether the sea level move up or down either from the shifting of the land mass or from the sea itself there will still be presented below sea level the constant factor of joint weakness in the mass of the earth itself to induce disintegration and further leveling; connecting in this manner land or

atmospheric erosion and marine erosion as two stages of a consecutive process.

There remains further the consideration of this in connection with the outlined shapes of the various continental shelves; the rapid descent of the lithosphere off these shelves being a general characteristic of all. The consideration of this subject must be with our limited information so largely speculative that it is not a subject which I now wish to discuss. The idea of attempting to carry the repeating patterns out to the sea floor beyond the limits of the shelves and to try to establish joint influence in the distribution of oceanic islands may however prove to be connected with the rise of blocked masses of the lithosphere.

It was proposed earlier in this paper to apply the method of "repeating patterns" to some island groups not connected closely to continental shelf land in order to draw a comparison if possible of similar jointing control in their distribution.

For the purpose of such comparison the following groups have been chosen though it is not by any means believed that these are the only ones which would yield concordant results; these are first the group of the Isles of The Shoals in the Gulf of Maine, secondly the Canary and Madeira group. With these for the sake of further development of the argument will be compared the islands of Oceania of the Pacific. It is not my intention to discuss in any detail the general geology of any of these groups, what it is desired to bring forth is their group morphology or more particularly the relations of their positions to each other. To consider the Shoals group first, this is a group of about seven actual islands with however a number of rock ledges which though submerged beneath the tide are an essential part of the construction of the whole group as may be seen from the navigation charts.³⁸ The figures or plotting of position are taken from chart 108.

The nearness to the present shore line of these islands with their rather evident similarity of position to other groups of islands in the same general vicinity makes no argument as to their essential connection with the mainland necessary. This is especially

³⁸ See Chart No. 108, Wells to Cape Ann, U. S. Coast and Geodetic Survey. Also U. S. Coast Pilot, Atlantic Coast, Pts. I. and II., pp. 142-143.

evident after an inspection of that portion of the waters and land masses along the Gulf of Maine. The positions of this group have been plotted by drawing lines connecting the greatest numbers of the islands including reefs which are regarded as islands. While the distribution of these islands is not so striking as the islands of Casco Bay to the north and east yet it is apparent that the application of the repeating pattern establishes here the existence of a fairly regular system of jointing which may be stated to control the position of this group as a series of upstanding residues of erosion from an older land surface, a small illustration of the more widely known case of the British Islands as remnants of a former series of connected structures all part of the mass of the continent of Europe.

With this plotting of the Shoal Islands may be compared the plotting of the positions of the Canary-Madeira group. I have used for this the map from C. Gagel³⁹ in his discussion of the islands of the middle Atlantic. (These were shown by lantern slides while reading paper.) The arrangement of practically all of these Atlantic islands shows lines of a parallel grouping so very similar to the development of continental volcanic vents and fissures along lines of separated segments or joints that it will hardly be disputed that the same principle has worked in each case. These islands consist in part, according to Gagel, of volcanic cones built up from the floor of the sea and in part are "broken remnants of the European-African continent."⁴⁰

According to Gagel three of the Canary group, namely La Palma, Fuertaventura and Gomera "show the undoubted representatives of very old volcanic, archean and sedimentary formations, which form the true sockets (=Socket) of the islands and prove themselves to be part of an old great continent, whose shattered fragments still appear in these islands." The other islands of this group consist of recent volcanic eruptives of Tertiary or Quaternary age carrying in some instances portions of marine Tertiary

³⁹ C. Gagel, "Die Mittelatlantischen Vulkaninseln," in "Handbuch der Regional Geologie," Vol. 7, part 10, Heidelberg, 1910, pp. 1-32. Here will be found the literature for this group noted and original references given.

⁴⁰ *Op. cit.*, p. 31.

sediments and in other cases as on Tenerif, Hierros and Antaos, the incoherent volcanics carry loose fragments of "older or at least coarsely crystalline rocks" which Gagel considers may have come from an older deep-seated "socket" or portion of the islands.

There is presented here then a construction in which may be seen two phases of joint influence, the broken and more or less symmetrically arranged fragments of residues of a continental structure, and secondly the rise of volcanic masses to the surface through the open fissures which lie between the aforementioned segments.

The Azores show likewise recent eruptive products with apparently no sediments earlier than middle Miocene; there is the further fact of deep sinking of the sea floor between some of these islands, as over 6,000 feet between Graciosa and Corvo.⁴¹

The general position of all these island groups of the Atlantic, their relations to the surrounding lithosphere shapes are all of importance; the positions of the Canary-Madeira group near the great adjustments incident to Mediterranean conditions, and the position of the Azores on the great Atlantic plateau are part of the general idea that these are all structures which are to be regarded as behaving in the same way as similar structures do on those portions of the lithosphere which are now continental. There are here evidences of the controlling action of a system of joints which are believed to have played their part not in surface degradation in the usual sense, but have been active in a system of movable segments which when under stress have resulted most probably in an essential up and down movement.

I have attempted to demonstrate block or joint development in the first place as an integral part of the lithosphere itself in a manner analogous to its presence shown in the larger land masses. That it has been the controlling factor in the disintegration of a former land mass represented by the islands now under discussion is too much to take as anything which can so easily be demonstrated. That it has been an active factor in marine denudation at this locus seems to me rather more than a supposition and appears as probable from the action of joint planes to produce an acceleration of marine degradation elsewhere. If these ideas be carried to the island

⁴¹ Gagel, *op. cit.*, p. 9.

groups of the Pacific such as the Solomon, New Caledonia, Kermadec, New Zealand groups there will be found an arrangement of island masses which have for many years suggested to geologists definite plans of group arrangement. It is not needful to detail these here as they are too well known to need review, having been considered so often in connection with the origin of coral reefs; a recent bibliography has been published by P. Marshall.⁴²

What seems to the present writer one of the most suggestive of recent theories in regard to these island structures in general was put forth by Alexander Agassiz in various studies published in the *Memoirs of the Museum of Comparative Zoology*.⁴³

As is of course well known the main ideas concerning coral islands in the Pacific have centered about the ideas of subsidence and numerous suggestions have been offered to satisfy this requirement. Agassiz in 1898⁴⁴ in discussing the reefs about Australia expressed the idea that too much emphasis had been laid upon subsidence and wished to bring in the factor of marine planation with "terraces of erosion" upon which coral masses would by natural extension grow together and form the Great Barrier Reef.

In later writings (*Memoirs*, Vol. XXVIII.) Agassiz has again cited marine erosion as developing the platforms upon which the reefs of various sorts would develop.

Given a water condition favorable to coral life there is no doubt that coral life would start along the rocky structures of the north Atlantic just as is now to be seen in the warmer seas. The problem here is not the coral life but rather the development of a platform upon which the coral organisms may persist. There can be little doubt that coral reef developments of various sorts would be found today along Madeira-Azores groups if the water conditions were favorable.

I would wish to suggest then that a profitable field for further study of coral life in the field in the Pacific islands may be found

⁴² P. Marshall, "Oceania," *Handbuch der Regional Geologie*, Vol. 7, pt. 2, Heidelberg, 1911. Reference may also be made to Suess, Dana, A. Agassiz, Murray and many others.

⁴³ See particularly *Mem. Mus. Comp. Zool.*, volumes from 1898 to 1903.

⁴⁴ *Bull. Mus. Comp. Zool.*, XXVIII., 1898; see also Agassiz, *Mem. Mus. Comp. Zool.*, XXVIII., 1903.

in the more careful study of these islands as developments from jointing or segmented structures.

The marked character of volcanic products from the island volcanoes, such as the successions of andesitic lavas supposed to be characteristic of the Pacific type compared for example with those from the Philippines which are much more varied though frequently andesitic, and with those from the Sandwich group which are essentially basic, may perhaps show some solution to the physiographic development of the region indicated.

That the igneous history of some of these groups has been a very long one is indicated by the same sort of reasoning as applied to rock masses elsewhere. This may be taken to mean a long period of time in which the segmented condition or open fissure condition has prevailed.

It is not accidental nor casual but from the evidence at hand we may with reason conclude that the surface of the lithosphere beneath the hydrosphere in this Pacific district of Oceania has been subject to tectonic movements, fissuring extrusion of igneous masses in a manner analogous to other parts of the lithosphere such as continental masses in which a jointing or block structure may be shown to be present.

Connected with this discussion is the general structure of the solid portion of the earth, now commonly referred to as the zones of fracture and flowage. These, as is known, are divided into more or less definite lines so that under certain supposed pressures rock masses will move in flow lines rather than in fracture lines, such as is indicated in many diagrams of mountain making. This may be regarded by some authors as a factor against the proposition of joint control which I have proposed. Further reflection, however, will suggest the thought that while the zones of fracture and flowage do represent definite differences in the behavior of the rock masses of the earth, that these lines of zone are not, however, fixed in their actual distance below the surface of the lithosphere. In other words, it is not only possible to conceive but I think the circumstances compel us to conceive of a certain rock mass passing from the flowage zone to the fracture zone by release of pressure. That is, if we take certain types of mountain structure represented

by the conventional lines of anticline and syncline structures,⁴⁵ a geosyncline, for example, or anticline would develop into a series of fractures in the outer portion of the lithosphere if the pressure which made the original fold were to continue or were to be applied without a heavy series of overlying beds. The zone of flowage would become a zone of fracture by release of pressure from above without necessarily there being a release of other strains in the mass of the rock. To make a practical application, the Appalachian folds and the fan-shaped folds of Heim, in the Alps, are often represented in diagrams as having developed as surface folds of the lithosphere, that is, it is practically stated that we might conceive a portion of the outer lithosphere structure to be practically destitute of faults from the fact that the rock structures under pressure assume a fold-flowage structure. Thus, in Fig. 285, in Pirsson & Schuchert, p. 362, the evolution of the Appalachian mountains is represented as having occurred as a series of zones of surface folding followed by erosion of the folded zone producing the usual peneplane. This I conceive to be at least an unlikely series of developments in spite of the weight of the authority back of the theory.

If the pressures which developed the Appalachians took place in a mass so that folding and flowage took place, we would almost of necessity have to suppose a heavy super-incumbent mass of rock, so that instead of fracturing taking place the rocks under the intense pressure would move by lines of flow; on the other hand if the above pressure were applied to a mass of rock without this heavy overlying weight, then fracturing would almost certainly have to follow. So, if in such a mass as the Appalachians where the force of the uplift continued through a long period of geologic time, with processes of surface erosion proceeding, it is an allowable supposition to believe that the zone of flow would pass upward into a zone of fracture and expose the outer portion of the lithosphere to a much more rapid means of degradation than would follow from the usual processes of erosion and degradation on an unfractured mass. So that the zone of flowage in this case, and it would apply to other

⁴⁵ See, for example, Figs. 285-291, Pirsson and Schuchert, "Textbook of Geology." Also Dana and others.

uplifted or folded areas, may be imagined to pass into a zone of fracture by a lessening of the distance between the outer atmospheric contact and the mass of rock in question. I do not wish to complicate the discussion by citing hypothetical cases, but we may perhaps legitimately imagine that folded areas such as the Appalachians and the Alps would continue to be subject to earth strains after erosion had removed a considerable part of the overlying weight of rock mass. This would then allow these folded masses to pass into fractured masses of various degrees of intensity. The bearing of this on joint control of degradation is, I think, obvious enough.

In connection with other courses of the rock mass of the earth which are not subject apparently to these intense pressures, such as the Canadian Shield, I have already stated that I believe the source of fracture there to be the successions of overloading by sedimentation, ice accumulation, marine inundation, with the consequent wearing out of the elasticity of the original rock mass. The rock mass under these circumstances would then simply proceed to fall apart, depending upon the presence of some agent such as marine erosion capable of removing the blocks due to jointing. The illustrations given of the disintegration of the mass of the coastal plain near Ogunquit, Me. (Figs. 5-6. Plate IX) will show practically how a mass of folded rocks will when exposed to release of pressure break down into segments which can easily be seen to be the result of wide reaching joints. Almost the whole coast of Maine is an illustration of this.

As for these rocks near Ogunquit, they show all the marks of what is usually referred to as rock bending under pressure, S-folds are not uncommon, isoclinal folds are evidently quite frequent and it is a very probable supposition that here is a mass of rock which has been under such stress that distinct folds developed and that now very definite lines of jointing are in control of the lowering of the land mass.

It is of course entirely possible or even probable that some of this jointing was simultaneous with the folding. I hope in a later paper to discuss the evidences for this.

But the essential fact stands out that here is a portion of the

stony portion of the earth passing into complete disintegration under the combined action of a great system of jointing which has already broken down the coherency of the mass, and under marine transportation (erosion).

It is my expectation in a later paper to present further results of the study of this locality.

From the discussion given, there may be deduced, then, the following propositions:

Proposition 1a.—That the lithosphere has certain constant physical factors which act universally and independently of local surface conditions: one of these is, for example, igneous action, and another is jointing.

Proposition 1b.—That this jointing develops as an essential result from the nature of the lithosphere itself which shows in practically all cases from continental masses to loose sands the regularity of lines of weakness.

Proposition 2a.—That surface features of the lithosphere, both sub-atmospheric and sub-oceanic, are controlled not by the agents of the atmosphere nor hydrosphere, but by the distribution of lines of master and minor joints.

Proposition 2b.—That surface drainage, glaciation, variations of weathering, may be regarded as accidental; that behind all of them, and also running ahead of them as the essential controlling factor, is jointing.

Proposition 3.—That joints have been present throughout all the geological history of the lithosphere, considered as possessed of solid portions.

Proposition 4.—That in the development of continental outlines, including continental shelves, and also in the development of surface continental features due to weathering and to atmospheric and marine erosion, the controlling factor is not atmospheric nor climatic nor marine primarily, but is due to the fundamental nature of the lithosphere itself as shown in its lines of jointing.

Proposition 5.—That the "repeating patterns" of authors which show joint control of the lithosphere on the continental surfaces may, with equal truth and value, be applied to the interpretation of the sub-oceanic lithosphere and that the distribution of oceanic

islands, volcanoes, reefs, and so on, may be explained by joint control of the structure of the lithosphere.

Proposition 6.—That jointing being a constant factor in the structure of the lithosphere and producing lines of easier displacement than folding, is one of the fundamental factors in the shifting of land and sea level, whether the shifting be regarded as having taken place under the hydrosphere or in the continental masses.

Proposition 7.—That jointing should be regarded by students of geophysics as an essential dynamic and constant factor in the behavior of the lithosphere and that it has been so practically throughout all geologic time.

Proposition 8.—Base line or base level of erosion is a term which refers to the results of atmospheric degradation and does not express the final results of continental land surface reduction. Since the relative positions of land and sea are known to be subject to change without any essential change in the character of the rock masses sea level can not be used as a term to express the equivalent of the lowest limit of continental land surface reduction or degradation.

From this there may be deduced principles which are proposed as a

LAW OF JOINTS.

1. The lithosphere is subject by its nature to the development of lines of weakness or fracturing which in turn develop into actual movable segments.

These segments or joint lines develop in such regularity of arrangement that they may be said to occur in "joint-systems" which are shown at the surface as controlling agents in land erosion and land shaping; and they act beneath the surface inducing tectonic movements which are independent of atmospheric or marine contact.

2. Degradation of the lithosphere is fundamentally a factor in its own structure and will occur whenever an agent capable of transporting the movable joint blocks is in contact with the lithosphere.

This applies to those portions of the land or rock mass below sea level.

3. Atmospheric erosion and marine planation are two separate phases of a general process of lithosphere degradation which are frequently connected into consecutive stages by the presence of joint lines which extend from beneath sea level up into the mass of the lithosphere above sea level; these lines are also horizontal and thus act to produce flat surfaces.

4. Degradation of the lithosphere surface may occur also by the vertical displacement of these joint segments irrespective of atmospheric or marine contact.

5. Joint control of lithosphere degradation has been active since the period when the lithosphere possessed a solidified structure and has been a fundamental factor in the evolution of the lithosphere, or geomorphology.

DETAILED OBSERVATIONS ON PLATES VI.-VIII.

PLATE VI., FIGS. 1 and 2. These sands are entirely unconsolidated but are rather gritty. Rehoboth Beach, Delaware.

PLATE VII., FIG. 3. Joint disintegration in quartz-mica-garnet schist, Prouts Neck, Maine. The loose segments fall to water level and through a pebble-gravel process are reduced to quartz and garnet sands, the mica washes to sea. The original rock character is thus totally destroyed by a rapid mechanical action working through joints.

FIG. 4. Boulder flat at Sea Point, Maine, above Portsmouth Harbor. This flat is composed of incompletely reduced joint blocks from the adjacent rock masses and appears to be built out over a reef which lies parallel to a series of other reefs and small rock segments in place. The flat is a prolific breeding and feeding ground for vast colonies of mollusca, small crustacea, lime secreting algae, *Laminaria* and other forms of animal and plant life. Angular blocks coated with lime carbonate are frequent. The relation of such boulder flats to life distribution suggests interesting paleographic analogies.

PLATE VIII., FIG. 5. Block disintegration proceeding in a folded area in coastal plain. The folds are now to be seen with their tops in most cases cut off and are broken into blocked segments. This fracture may be seen to extend below the level of the cliff. Near Ogunquit, Maine.

FIG. 6. Angular edges forming an abrupt series of sea terraces. The entrance of one of a series of parallel coves or small bays may be noted. In front of the cliff extends a broad platform induced by the horizontal jointing. Cliffs near Ogunquit, Maine.

(All of the illustrations are from photographs taken by the author.)